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MATLAB PROGRAM FOR TRADITIONAL DESIGN AND OPTIMIZATION OF 30 KW SCIM MOTOR

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ABSTRACT

Various steps in development of a MATLAB program for the traditional design of 30 KW SCIM motor have been detailed. The whole process of traditional design of motor design is divided into five parts and again each part into various steps. The MATLAB program listed performs all the activities associated with five parts and their steps of the process. Relevant comments are added into the MATLAB program at suitable locations to identify the calculations associated. Parameters of design of motor and the equivalent variables used in the MATLAB program of steps of design process under each part are listed in the relevant tables. The list of variables used and equivalent MATLAB variables completely bring clarity to the steps followed in the traditional design of the motor.

KEYWORDS: MATLAB Program, SCIM Motor, Traditional Design of Motor & Parameters of Design of Motor

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Original Article

I INTRODUCTION

Several methods of reduction of losses have been identified and reported in report [3] by the same authors of this report. As part of the thermal design improvement of Squirrel cage induction motor (SCIM) motors which forms the main focus of the thesis work of author 1, this MATLAB program is developed to study the effects of reduction of losses due to the techniques adopted and detailed in the above report.

In this report step by step traditional procedural design based evaluation of motor along with optimisation both for round conductors and bar conductors of a 30 KW SCIM motor has been presented. The MATLAB program listing is provided as the annexure. In the text book [1] two MATLAB programs, one for the evaluation of motor parameters and the other for optimisation of parameters for a 30 KW motor are explained. This MATLAB program is an improvement compared to the two MATLAB programs combined of text book [1] from the following aspects. In the present report both of these have been combined into one single program, with a value of variable OPTIM being given a value equal to 1 (motor optimisation) or Option 0 (No optimisation).

II MATLAB PROGRAM FOR TRADITIONAL DESIGN AND OPTIMISATION OF MOTOR

Various steps in the overall design of motor using MATLAB program have been explained with tables and equations and the corresponding MATAB expressions have been indicated with suitable comment statements. For a 30 KW motor many manufacturers still prefer to have round conductors; at the same time usage of bar

conductors also exists. So the provision of designing with both types of conductors is made available in the program. When round conductors are used; it is a common practice to use tapered slots and straight teeth. The slot area in the program corresponds to the mean area of tapered slots assuming a fixed taper for all the slots. Mean height to mean width ratio of the slot is a parameter of variation of optimisation. And slot fill factor has been the other parameter of optimisation. Report [2] gives the sequential steps provided in the traditional design of a motor but the traditional design is done using hand calculations which do not cover the scope for automation of design of motor. The values of detailed calculations have been provided for bar conductors (cond_type=2) and the output values are provided for rod conductors (cond_type=1) with optim variable value equal to 0. Optimisation results of the program for rod conductors and bar conductors are given in tables XXXXI and XXXXII. Optimisation of slots with different stator and rotor slot profiles and air gap lengths for number of laminations (n_lams) also has been made available in this program for a given value of n_lams. In the present program provision for n_lams has been made for a value of 4 but the values have been given same and n_lams is given equal to 1.

Table 1 gives the listing of details of variables corresponding to motor parameters used in the mathematical expressions and equivalents of MATLAB program.

Table 1

Part I		
MATLAB Variable	**Used for**	**Variable used in Equations**
SKW	KW power of motor	------
SBav	Average flux density	B_{av}
SKWa	Kilo watt power of motor	---------
ac/m (sq)	Electrical power density	q
Vph	Volts per phase	V_{ph}
f	frequency	f
FI	Flux φ	φ
ki	Iron factor	---
C0	Output coefficient	C_0
SPF4P	Power factor values at the given rated power	------------
SEF4P	Efficiency values at the given rated power	------------
KW	Kilo watt of motor	Q
V	Voltage	V
Iph	Current per phase	I_{ph}
PP	Pole Pitch	$\tau=\frac{\pi D}{P}$
LbyPP	Length/Poe Pitch	L/τ
P	Number of poles	p
v	Peripheral velocity	v

Table 2 gives the values and units of the parameters corresponding to name plate details of a motor.

Table 2: Name Plate Details of 3 Phase 4 Pole SCIM Motor

Parameter	MATLAB Variable	Variable	Units	
Rated power	KW	Q	[KW]	30
Phase voltage	V	V_{ph1}	V	690
Input phase current	Iph	I_{ph1}	A	27.07

Table 2: Contd.,				
Synchronous speed	Ns	N_s	rpm	1500
Supply frequency	f	f	[Hz]	50
Targeted power factor:	pf	$\cos\phi$	--	0.84
Targeted efficiency:	eff	η	--	0.927
Lamination thickness	DELT	Δ	mm	0.5
Shaft diameter	riry	r_{iry}	mm	110
Sots/pole/phase	spp	q_s/q_r	--	4
Winding factor	Kw	K_{pd1}	--	0.955

A. Limitations in Design

Table 3: Selection Criterion for Physical Dimensions of Motor

	Range of (L/τ)	Will Yield/ Result
a)	1.0 to 1.1	Good overall design
b)	1.0 to 1.3	Good power factor
c)	1.4 to 1.6	Good efficiency
d)	1.5 to 2.0	Minimum overall cost

The materials used for the machine imposes a limitation in design. The limitations stem from saturation of iron, current density in conductors, temperature, insulation, mechanical properties, efficiency, power factor etc.

III STEP 2 OF PART I - DESIGN CRITERION FOR BASIC DIMENSIONS OF STATOR

Main physical dimensions of motor are obtained to achieve the design criteria which are obtained based on ratio of gross length and pole pitch Ratio (L/τ) as explained below:

Table 4: Physical Dimensions of Motor

Step 2of Part I Physical Dimensions of Motor			
	MATLAB variable	Variables used in Equations	
Diameter of Stator	D	D	0.213
Gross Length	L	L	0.207
D^2 L	DsqL	D^2L	0.0112
Net Iron Length	Li	L_i	0.190

Table 5: Average Performance of Class 2 Motor

Speed	Performance at rated output			
	Torque Nm	Current	η	pf
1465	195	58	91.6	0.82
η	For DL stator Pu I_S/I_n	Break down torque T_s/T_n	T_{max}/T_n	
91.6	6.6	2.4	2.8	

Efficiency Class = 2 T_s= Starting torque I_s = Starting current

III STEP 3 OF PART I BEARING AND FRAME

The frame sizes are generally standard and are made of either Al alloy or CI. Al alloys are better conductors of heat where as cast iron material has higher strength. Motors made of better tolerances and lower values of air gap have

better heat dissipation from rotor to stator and then to environment.

Table 6: Bearing and Frame Details of Motors

Frame Details	Bearings		Radial Ball Bearing Details		
	DE Side	NDE Side	Bore	OD	3Width
200 L	6312	6312	60	130	31

IV. STEP 4 OF PART I - MAGNETIC AND ELECTRIC LOADS SELECTION

Iron losses largely depend upon air gap flux density

Table 7: Advantages of Higher Value of B_{AV}

Size of the Machine Reduces	Cost of the Machine Decreases	Overload Capacity Increases

Table 8: Selection Criterion for Physical Dimensions of Motor

ac/m	The Value of Electric Loading Varies between 5000 and 45000 i.e. $5000 \leq ac \leq 45000$
Interpolate specific electric loading ***ac/m*** (ampere conductors per meter of air gap circumference) from Table 8. The value of ac/m determines how heavily the electric material is utilized. High ***ac/m*** means less electric material but higher electric losses.	

Table 9: Dependence of Iron Losses on Air Gap Flux Density

B_{av}	B Lies between 0.35 and 0.53 i.e $0.35 \leq B \leq 0.53$ and the Suitable Values Can be Interpolated from the KW Value of the Motor Selected.
B_{max}	The Maximum Flux Density Commonly Employed is between 2.2T to 2.4T.
Select $\mathbf{B_g}$ from **experience** (limited by losses in the teeth and magnetizing current). B_g depicts how heavily the magnetic core material is utilized. High $\mathbf{B_g}$ means less magnetic material but higher magnetic losses. Select magnetic material also based on frequency.	

V. STEP 5 OF PART I - VALUES OF INTERPOLATION

Tables X, XI and XII give the values of B_{av} and q, efficiency and power factor values selected from Design data hand book for the given motor power.

Table 10: Values of B_{AV} and ac/M for 30 KW Motor

KW	1	2	5	10
B_{av} (T)	0.35	0.38	0.42	0.48
ac/m (q)	16000	19000	23000	25000
KW	20	50	100	500
B_{av} (T)	0.48	0.50	0.51	0.53
ac/m (q)	26000	29000	31000	33000

Table 11: Power Factors vs. Motor Power

SKWa	5	10	20	50	100	200	500
SPF4P	0.85	0.86	0.88	0.90	0.91	0.92	0.93

Table 12: Values of Efficiency for Different Motor Powers

SKWa	5	10	20	50	100	200	500
SEFF4P	0.85	0.87	0.88	0.90	0.91	0.93	0.94

Table 13: Values of Current Densities -Vs Rotor Diameters

Diameter in Meters	0.1	0.15	0.2	0.3	0.4	0.5	0.75	1
J A/mm^2	4	3.8	3.6	3.5	3.5	3.5	3.5	3.5

Table 14: B-H Curve for 0.5mm LOHYS Material

B	**.1**	**.2**	**.3**	**.4**	**.5**	**.6**	
H	50	65	70	80	90	100	
B	.7	.8	.9	1	1.1	1.2	1.3
H	110	120	150	180	220	295	400
B	1.4	1.5	1.6	1.7	1.8	1.9	2
H	580	1000	2400	5000	8900	15000	24000

Carters' coefficients are available for the ratio of the slot width and the air gap vs carter coefficient and are tabled as below.

Table 15: Carters Coefficients

Ratio	**0**	**1**	**2**	**3**	**4**	**5**	**6**
For open slots	0	.18	.33	.45	.53	.6	.66
For closed slots	0	.14	.27	.37	.44	.5	.54
Ratio	7	8	9	10	11	12	
For open slots	.71	.75	.79	.82	.86	.89	
For closed slots	.58	.62	.65	.68	.69	.7	

Table 16: Flux Density vs WPKG (Power Loss of Watts Per Kg)

B	0.8	1.2	1.6	2.0	2.4
WpKg	7	15	24	34	50

VI. OUTPUT COEFFICIENT (C_0) ESTIMATION ---- GOVERNING EQUATIONS

Output of a SCIM motor is also equal to

$$Q = 3\ V_{ph1} \times I_{ph1} \times \cos(\varphi) \times \eta \times 10^{-3}\ \text{KW} \quad (1)$$

Or equation (2) can also be written as

$$Q = 3(4.44 \times K_{pd1} \times f \times \varphi_m \times N_{ph1} \times I_{ph1} \times \cos(\varphi) \times \eta \times 10^{-3} \quad (2)$$

(Since $V_{ph1} = 4.44 \times K_{pd1} \times f \times \varphi_m \times N_{ph1}$) and

$$\varphi_m = B_{av} \times \tau \times L = B_{av} \times \frac{\pi D}{P} \times L$$

Total No of conductors on Stator = 3 x 2 N_{ph1} = 6 N_{ph1}

Total Ampere Conductors on Stator = 6 N_{ph1} I_{ph1} which is known as total electric loading

Specific electric loading: It is defined as electric loading per meter of periphery, denoted by ac

ac = $\frac{6N_{ph1} I_{ph1}}{\pi D}$ or $N_{ph1}\, I_{ph1} = \frac{\pi D\ ac}{6}$

By substituting the values of f, φ_m & N_{Ph1} I_{Ph1} in equation (2)

$$Q = 3 \times 4.44 \times 0.955 \times (\frac{nsP}{120}) \times (B_{ave} \times \frac{\pi D}{P} \times L) \times \frac{\pi D\ ac}{6} \times \cos\varphi \times \eta \times 10^{-3}\ KW \quad (3)$$

$$Q = (17.4 \times 10^{-5} B_{ave}\ ac \cos\varphi \times \eta)\ D^2 Ln_s \quad (4)$$

Or $Q = C_o D^2 Ln_s$

Where C_o = Output Co-efficient = $(17.4 \times 10^{-5} B_{ave}\ ac \cos\varphi \times \eta)$

Output equation relationship between electrical rating and physical dimensions (Quantities) or the D^2L equation relating output power (Q), synchronous speed (ns) and rotor volume through an output coefficient (C_0) is as given in Eq. (1) below:

$$C_o = \frac{Q}{kw_s n_s D^2 L.} \quad (5)$$

The VA (Q) rating is proportional to

- The average gap flux density B;
- The armature surface current density ac;
- The volume of the rotating member, D^2L product and the speed of rotation, n_s.

Table 17: Electric and Magnetic Parameters of Motors

	MATLAB variable	**Variable used in Equations**	**Units**	
Rating	SKW	Q	(KW)	30
Volts	Vph	V_{ph}	Volts	398
Step 5 Interpolated Values from Tables I to III				
Average flux density	SBav	B_{av}	tesla	0.484
ac/m (q)	q	q	amp cond/m	26802
Efficiency	eff	η	--	0.892
Power factor	pf	Cos(φ)	--	0.885
Step 6 Motor Parameters				
Output coefficient	Co	Co	Ws/m^3	107.61
Synchronous speed	ns	n_s	rps	25.00
Peripheral Speed	v	v	(m/s)	16.73
MAXIMUM PERMISSIBLE IS 30 M/SEC				

Because the contains air gap flux density (B_g) and surface current density (K_1) in Eq. (2), where α is the magnetic saturation factor, K_{w1} is the winding factor.

D^2L equation has no relationships connecting air gap quantities with the flux density and current densities existing in the motor's interior.

Table 18: Effect of Slots on Design

Less slots
• Less cost • Less space lost due to insulation and slot opening
More slots
• Smaller leakage inductance and larger breakdown torque • Small MMF harmonics • Better cooling

VII. DESIGN OF STATOR (PART II)

Step 1 of Part II

In this step all the stator dimensions corresponding to the stator poles are estimated.

Table 19: Variables Corresponding to Design of Stator and Equivalent MATLAB variables

Step 1 of Part II		
sp	Slot Pitch	yss
Tph	Turns per phase	N_{ph}
CDSW	Current Density	j
j	Current per phase	I_{ph}
inSW	Width wise insulation	w_{in}
hstrip	Height of strip	h_{strip}
HW	Height of wedge	h_w
HL	Height of Lip	H_l
Zph	Conductors per phase	Z_{ph}
Zsh	No of conductors height wise in slot	Z_{sh}
insH	Height wise insulation	h_{ins}
Zs	Conductors per slot	Z_s
Step 2 of Part II		
Bt_{max}	Max flux density of the tooth	Btmax
Rph	Resistance/phase	R_{ph}
L_{mt}	Length of mean turn	L_{mt}
P_{cus}	Copper loss	$P_{cu,s}$
Step 3 of Part II		
Hc	Height of core	h_c
FIc	Flux in core	φ_c
Do	Core outer diameter	D_o
Ac	Area of core	A_c
Step 4 of Part II		
PitpKg	Iron loss in tooth/kg	P_{it}’
Pit	Iron loss in tooth	P_{it}
Wt	Weight of tooth	W_t
PicpKg	Iron loss in core/kg	P_{ic}’
Pic	Iron loss in core	P_{ic}
Wc	Weight of core	w_c

VIII. DESIGN OF SLOT SIZE

Fill factors of 0.4 and 0.5 are used for stator slots when round conductors are packed in slots, and outer diameter of slots is calculated where as this could be close to 1.0 for rectangular cross section conductors. Number of conductors per slot is found such that flux density is within permissible limits of the material used. Semi-closed and trapezoidal (with rounded corners) stator and rotor slots with rectangular teeth are designed for this motor.

The influence of number of stator slots is as given below table.

IX. STEP 2 OF PART II- STATOR SLOT GEOMETRY

There are two types of slots namely: a) Partially open (semi) and b) Closed Slot

For small motors, taper on the tooth or slot is significant and tapered slots (and parallel sided teeth) are used. This gives maximum area of slot for given tooth flux density. Round wires of small gauge are used since they are easy to wind and do not mind the taper of the slot.

Table 20: Details of Conductor Arrangement in Stator Slot

Slots	S_1	S1	48
Slot Pitch (mm)	yss	$\pi D/S_1$	13.941
Slot pitch provided is close but less than ideal range of 15 to 20 mm. The slot pitches provided are acceptable for partially (semi) closed slots (Tapered slots and parallel teeth)			
Conductors/Slot	N_{c1}	Zs	21
SLOT-PITCH(MM) (PERMISSIBLE:18TO25MM)			
Turns/Ph	Tph	N_{ph}	120
No. of conductors /phase	Zph	Z_{ph}	240
Flux/Pole(Wb)	Fipp	φ/p	0.01566
Phase Current (A)	Iph	I_{ph}	31.78
STEP 2 OF PART II			
Bare Strip (w*t)mm	Hst,Tst	w_{st},t_{st}	5.50X1.55
Width to Thickness Ratio	hstbytst	$w_{st},/t_{st}$	3.55
(Permissible:2.5to3.5)			
Area of CS cond(mm^2)	As	A_s	8.244
Current density(A/mm^2)	CDSW	j	4.000
No of Strips (width*depth -wise)	Zsw	Z_{sw}	3 X 5
Slot-Width (mm)	Wsl	W_{sl}	9.5
Slot-Height(mm)Total	hsl	h_{sl}	43.0

X. CROSS SECTIONAL AREA OF STATOR CORE

The cross section area of stator core A_{cs} is given by

$A_{cs} = (\Phi m/2)/ B_{cs}$ Here, Bcs is flux density in stator core, which is taken about 1.2 Tesla.

Stator teeth width Value selected should be between 6.4 mm and 25.42

Ratio of slot width to slot pitch Value selected should be between 0.4 and 0.6 - Ref of Lipo

Depth of stator core $d_{cs} = A_{cs}/L$ (6)

Outer dia of stator, Do = (D+2.dss + 2.dcs) (7)

Table 21: Core Details of Stator

O.D. of Stator	Do	D_o	mm	330.0
Copper c/s in slots	Acs	A_{cs}	mm^2	8.366
No. of conductors /slot	Zs	Z_s	--	18

XI. STATOR SLOT DIMENSIONS

Area of one stator slot A_{ss}= Z_{ss}/space factor (Space factor lies between 0.25 and 0.4)

For parallel sided slot of stator, minimum tooth width of stator, is given by-

$W_{ts\ min}$ = (P. Φm)/(1.7 L. Ss) (Here, maximum allowable flux density in stator tooth is 1.7 T)

XII. SLOT SPACE FILL FACTOR FOR OBTAINING SLOT DIMENSIONS

High voltage machines have lower space factors due to large thickness of insulation. The slot should not be too wide to give a thin tooth. The width of the slot should be so adjusted such that the mean flux density in the tooth lies between 1.3 to 1.7 Tesla. Width of tooth should not be too large as it results in narrow and deep slots. Deeper slots lead to larger value of leakage reactance. In general the ratio of slot depth to slot width should be between 3 and 6.

Per phase stator current, $I_{ph1} = \frac{Q\ x\ 10^3}{3V_{ph1}\ Cos\varphi\ \eta}$ (8)

$F_{c1} = \frac{I_{Ph1}}{\delta_1}$ (9)

F_{c1} = area of stator conductor

Current density δ1value is obtained from the interpolated value of plot from data available for Stator diameter vs current density values

XIII. STEP 3 OF PART II - FLUX DENSITY ESTIMATION IN STATOR TEETH

For estimation of flux density in stator teeth various details of stator are estimated at a distance of 1/3 of tooth height from narrow end of stator tooth.

Maximum flux density in stator tooth should not exceed 1.8T; otherwise iron losses and magnetizing current will be abnormally high. (So if flux density >1.8T, change slot dimensions)

Mean flux density in the stator tooth is calculated at $\frac{1^{rd}}{3}$of tooth height from the narrow end of the stator tooth.

Diameter of stator at $\frac{1^{rd}}{3}$of tooth height from narrow end

$D_{\frac{1}{3}h_t}$ = D + $\frac{1}{3}$ h_s x 2 (10)

Slot pitch at $\frac{1^{rd}}{3}$of tooth height from narrow end

$\tau_{sg\frac{1}{3}h_t} = \frac{D_{\frac{1}{3}h_t}}{S_1}\ \pi$ (11)

Width of the tooth at $\frac{1^{rd}}{3}$ of tooth height from narrow end

$$b_{t\frac{1}{3}h_t} = \tau_{sg\frac{1}{3}h_t} - b_s \quad (12)$$

Area of one stator tooth at $\frac{1^{rd}}{3}$ of tooth height from narrow end

$$= b_{t\frac{1}{3}h_t} \text{ x } K_i\, l \qquad \text{(Where } l_i = k_i\, l = \text{Actual iron length)} \quad (13)$$

Area of all the stator teeth under one pole

$$A_{t\frac{1}{3}h_t} = \text{Area of one tooth x (No of teeth per pole or } \frac{S_1}{P}) = b_{t\frac{1}{3}h_t} \text{ x } K_i\, l \text{ x } \frac{S_1}{P} = \left[\frac{\pi\left(D+\frac{1}{3}h_s\, x\, 2\right)}{S_1} - b_s\right] x\, K_i\, l \text{ x } \frac{S_1}{P} \quad (14)$$

So mean flux density in teeth

$$B_{t\frac{1}{3}h_t} = \frac{\varphi_1}{A_{t\frac{1}{3}h_t}} \quad (15)$$

Table 22: Slot Details at 1/3 Height from Narrow End

Slot Details at 1/3 Height from End			
Diameter Equation (10)	D13	$D_{\frac{1}{3}h_t}$	241.6667
Slot Pitch Equation (11)	sp13	$\tau_{sg\frac{1}{3}h_t}$	15.8170
Width Equation (12)	Wt13	$b_{t\frac{1}{3}h_t}$	6.2670
Mean Flux Density Equation (15)	B13	$B_{t\frac{1}{3}h_t}$	1.0933
Tooth Flux Density Max(T)	Btmax	Bt_{max}	1.6400

XIV. STEP 4 OF PART II - COPPER LOSSES IN STATOR WINDING

Mean length of turn of stator winding (L_{mt1})

$$L_{mt1} = 2\,L + 2.3\,\tau + 0.24 \quad (16)$$

Resistance of stator winding per phase (R_{Ph1})

$$R_{ph1} = 0.021 \text{ x } 10^{-6} \frac{L_{mt1}}{F_{c1}} \text{ x } N_{ph1} \quad (17)$$

(Only bar conductors are used) Total copper loss in stator winding= 3 $I_{ph}^2\, R_{ph1}$ (18)

Table 23: Copper Losses in Stator Winding

Length of Mean-Turn (m)	Lmt	L_{mt1}	1.039
Resistance/Ph (ohm)	Rph	R_{ph1}	0.3175
depth of Stator Core(mm)	Hc	h_c	30.50
Outer Diameter of Stator Core(mm)	Do	D_o	360.0
Stator Copper Loss(W)	Wcus	$I^2\, R_{ph1}$	961.9

$P_{i,t}$ = Iron loss in teeth = $p'_{i,t}$* 7860 * volume of iron teeth

$P_{i,c}$ = Iron loss in core/yoke = $p'_{i,c}$* 7860 * volume of iron yoke

Iron loss in yoke = = $P_{i,y}$ * Weight of iron in yoke

Table 24: Iron Losses in Stator

Interpolated Values of W/KG			
Stator Teeth	pitpkg	$P'_{i,t}$	24.91
Core	picpkg	$P'_{i,c}$	18.32
Weight of Stator (KG)			
Teeth	wt	w_t	19.21
Core	wc	w_c	46.83
Total	wst	w_{st}	66.04
Iron Losses in Stator			
Teeth (W)	Pit	$P_{i,t}$	478.6
Core (W)	Pic	$P_{i,c}$	858.1
Total	Pisto	$P_{i,s,to}$	1336.7

XV. STEP 5 OF PART II -CHECK FOR FLUX DENSITY IN STATOR TEETH AND YOKE

Table 31 is used for checking the limits. Stator laminations are made of Silicon steel in all the three motors and the stator core loss coefficient corresponding to lamination steel is interpolated as per table 15 corresponding to 50 Hz frequency. Flux through stator yoke is equal to half of the flux through flux per pole

Thus $B_y = \frac{\varphi_1}{2\, l\, h_y K_i}$ and flux density in yoke should be in the range of 1.3 to 1.5 T

Corresponding to flux densities in core and tooth of stator B_y and $B_{t\frac{1}{3}h_t}$ find out values ($p'_{i,t}$ and $p'_{I,y}$) iron loss per Kg from the graph or interpolate the values corresponding to table

XVI. STEP 1 OF PART III - ROTOR DESIGN

Air gap provided is fixed in the MATLAB program but the program is structured such that there is a provision for varying the air gap value and optimizing the slot parameters for achieving further optimization of the motor.

XVII. STEP 2 OF PART III NUMBER OF ROTOR SLOTS

Table 25: Dimensional Details of Rotor and Slot

Design Details of Rotor and its Windings			
Length of Air gap(mm)	lg	l_g	0.8000
Diameter of Rotor (mm)	D	D	211.8
Rotor Slot Pitch (mm)	spr	yss_r	17.0580

Number of rotor slots that should not be used has been listed such that the slot combinations are suitable for stator and rotor for the given poles of the motor. The suitability is to avoid cogging, crawling and magnetic noise for the squirrel cage motor. Similar to air gap value the number of suitable rotor slots also may be optimised to get the best performance of the motor. This has not been done in the program.

Table 26: Selection of Number of Rotor Slots

Slots should not be equal to:	36,44,40, 28
Should not be equal to	47,46,41,40
No of Rotor Slots Selected	39

XVIII STEP 3 OF PART III – ROTOR COPPER LOSSES

In this step equivalent rotor current, Size of rotor bars are calculated.

- **Equivalent Rotor Current (I_{ph2})**

It is assumed that 85% of ampere turns get transferred to the rotor Ampere turns on stator = 3 I_{ph1} N_{ph1}

Ampere turns on rotor = $I_{2bar}\frac{S_2}{2}$ So$I_{2bar}\frac{S_2}{2}$ = 0.85 x 3 I_{ph1} N_{ph1} Or

$$I_{2bar} = \frac{0.85\ x\ 6\ I_{ph1}\ N_{ph1}}{S_2} \quad (19)$$

End ring current $I_{2endring} = \frac{S_2\ x\ I_{2bar}}{\pi P}$ (20)

- **Size of Rotor Bars or Rotor Conductors**

Cross sectional area of rotor bar

$$F_{c2bar}\frac{I_{2bar}}{j_{bar}} \quad (21)$$

Cross sectional area of rotor end ring

$$F_{c2endring} = \frac{I_{2endring}}{j_{endring}} \quad (22)$$

- **Design Calculations of Rotor Bars**

Selection of cross section of bars and end rings is a compromise between a) High rotor resistance which gives good starting torque and b) Low rotor resistance which gives low copper losses. Rotor bar (width to depth) geometry depends on the torque-speed characteristics and starting torque values.

For a continuous service motor with high value of efficiency requirement low rotor resistance is aimed at. Rectangular shaped bars and slots are generally preferred in rotor.

Current density in rotor bar is = 5 to 7 A/mm^2 for copper materials and for aluminium bar, the range is 2.2 to 4.5 A/mm^2 and a higher limit value is chosen for motors analysis.

Generally rotor bars and end rings are made of Aluminum material and stator conductors are made of copper material. It may be observed that the values are higher than stator conductors because rotor conductors are bare that is no insulation so better heat conduction resulting in better cooling so j is more. Current density in end ring is same as current density in bar.

Table 27: Design Calculations of Rotor Bars and End Rings

Step 3 of Part III			
Equivalent Rotor Current(A)	Ir	I_{ph2}	27.01
Rotor bar Current(A)	Ib	I_{2bar}	476.2
Rotor bar CS(mm^2)	Ab	F_{c2bar}	82.3200
Bar (w*t)mm	a_b (w*t)	F_{c2bar} (w*t)	14.0X 6.0
Rotor Slot	sw,sh	(w*h)	14.5x6.5
Length of Bar (m)	Lb	L	257.000

Resistance/bar(m.ohm)	Rb	R_b	0.0656
Losses in Rotor Bars (W)	Pcub	P_{cub}	579.8
End ring Current	Ie	$I_{2endring}$	1477.9
Area of end ring (mm^2)	Ae	$F_{c2endring}$	246.3
Resistance of end ring(m.ohm)	Re	R_e	0.0433

Select current density in rotor bars and end rings and from rotor bar and end ring currents get their cross sectional areas.

Calculate rotor bar and end ring resistances and hence copper losses. Equivalent rotor resistance is equal to total rotor copper losses divided by rotor current. Value of slip at full load is determined by rotor resistance.

Resistance of one bar = 0.021 x $10^{-6} \frac{L}{F_{c2bar}}$

Cu loss in bars = S_2 x I_{2bar}^2 x Resistance of end ring

$$= 0.021 \times 10^{-6} \frac{(m)\,\pi\,(D-2g-\,2\,d_{2bar})}{F_{c2end\,ring}} \quad (23)$$

Cu loss in end rings = 2 x $I_{2endring}^2$ x Resistance of one end ring (24)

Total cu loss = Cu loss in bars + Cu loss in end rings

Table 28: Rotor Copper Losses - Step 3 of Part III

Used for	MATLAB variable	Variable used in Equations	Value
Bars	Pcub	P_{cub}	579.8
End.rings	Pendring	$P_{endring}$	189.3
Total	**Pcu,r**	$\mathbf{P_{cu,r}}$	**769.1**
Equivalent Rotor res Ω	Rr	R_r or R_2	0.351

XXIII STEP 4 OF PART III – PARAMETERS AT 1/3 POSITION FROM NARROW END

- **Flux Density in Rotor Tooth and Core**

  Note: The value of flux density in rotor tooth and core is same as flux density in stator tooth

Diameter of rotor at $\frac{1^{rd}}{3}$ of tooth height from narrow end

$$D_{t\frac{1}{3}h_{t2}} = D - 2\,\mathrm{lg} - \frac{2}{3}\,h_{t2} \times 2 \quad (25)$$

End ring depth = Rotor bar (slot depth) + clearance

Slot pitch at $\frac{1^{rd}}{3}$ of tooth height from narrow end

$$\tau_{sg2\frac{1}{3}h_{t2}} = \frac{D_{t\frac{1}{3}h_t}}{S_2}\,\pi \quad (26)$$

From Narrow End

Width of the tooth at $\frac{1^{rd}}{3}$ of tooth height

$$b_{t2\frac{1}{3}h_{t2}} = \tau_{sg2\frac{1}{3}h_{t2}} - b_{s2} \tag{27}$$

Area of one stator tooth at $\frac{1^{rd}}{3}$ of tooth height = $b_{t2\frac{1}{3}h_{t2}}$ x $K_i\ l$ (28)

Area of all the stator teeth under one pole

$A_{t2\frac{1}{3}h_{t2}}$ = Area of one tooth x No of teeth per pole

$= b_{t2\frac{1}{3}h_{t2}}$ x $K_i\ l$ x $\frac{S_2}{P}$

$$= \left[\frac{\pi\left(D-2\delta-\frac{2}{3}h_{t2}\ x\ 2\right)}{S_2} - b_{s2}\right] x\ K_i\ l \text{ x } \frac{S_2}{P} \tag{29}$$

So mean flux density in teeth

$$B_{t2\frac{1}{3}h_{t2}} = \frac{\varphi_1}{A_{t2\frac{1}{3}h_{t2}}} \tag{30}$$

Details of the rotor at $\frac{1^{rd}}{3}$ depth from the narrow end of rotor tooth section

Length of magnetic path =Pitch of rotor at $\frac{1^{rd}}{3}$ depth from minimum dimension of bar = L_m

Tooth width at bottom T_b

B_s = Rotor Tooth Average Flux density at 1/3 position

XXIV PARAMETERS AT THE POSITION OF 1/3 HEIGHT FROM NARROW SLOT END

Parameters at 1/3 height from narrow slot end are evaluated to evaluate the average flux density

Table 29: Parameters at 1/3 Position from Narrow End of Slot

Used for	MATLAB Variable	Variable used in Equations	Value
Rotor Slot-Pitch(mm) Equation (28)	SPr13	$\tau_{sg2\frac{1}{3}h_{t2}}$	17.0580
1/3 Position			
Slot-Pitch(mm)			15.50
tooth width(mm) equation (29)	Wtr13	$b_{t2\frac{1}{3}h_{t2}}$	9.00
Tooth-Flux-Dens (1/3) (T)	Brt	$B_{t2\frac{1}{3}h_{t2}}$	0.9369
Tooth-Flux-Dens-Max(T)	Brtmax	Brtmax	1.4054
(Permissible:1.2 to 1.5)			
Depth of Rotor core (mm)	dcr	$d_{c,r}$	30.45

XXV STEP 1 OF PART IV NO LOAD PARAMETERS

Estimation of No load parameters especially the no load current and no load torque and ensuring that they are not very high is very important for the good design of motor. Aluminium is lighter and has good forming characteristics so that

aluminium conductors may be ensured to have perfect contact between the slots and conductors. Copper offers low electrical and thermal resistances but perfect thermal contact may not be ensured if the conductors are not to be moulded. Moulding temperature associated problems have to be handled to consider copper conductors for moulding.

Table 30: Variables and their Equivalents of MATLAB -Part IV

Part IV		
MATLAB Variable	**Used for**	**Variable used in Equations**
PnL	No load loss	P_{nL}
Iw	No load phase current	Iw
Stator		
ATSC	Amp-turns for stator core	ATSC
Pf0	No load power factor	Pf0
ATST	Amp turn for Stator teeth	At2ht1
Spitch	Stator Slot Pitch	Spitch
atst	Amp-turns/m for stator teeth	at2ht1
ATS	Total AT for stator	ATS
Rotor		
Wss0	Stator slot opening	Wss0
Spitch	Rotor slot pitch	Spitch
k01	Carter coefficient	k_{01}
K02	Carter coefficient	K_{02}
Spr0	Rotor slot pitch near air gap	Spr0
Wsr0	Rotor slot opening	$W_{0,r}$
kgr	Gap coefficient for Rotor Slots	K_{c2}
kgs	Gap coefficient for Stator Slots	K_{c1}
kg	Air gap coefficient	kg
Lgd	Effective air gap	l_g’
Aag	Air gap area/pole	A_{ag}
Bg	Flux density in the air gap (Bg)	Bg (37)
B30d	Gap flux density at 30 from the centre of pole	B_{30}
Btr30	Gap flux density in rotor tooth at 30 from the centre of pole	Btr30 (38)
atrt	Amp-turns/m for Rotor tooth	$at_{r,t}$
ATRT	Amp-turns for Rotor tooth	At2ht2
atrc	Amp-turns/m for Rotor core	$at_{r,y}$
ATRC	Amp-turns for Rotor core	$AT_{r,y}$
Im	Magnetising current	I_m
I0	No load phase current	I0

The performance of the motor without load or starting of the motor is given by the following table.

Table 31: No Load Parameters

Used for	**MATLAB variable**	**Variable used in Equations**	**Value**
NO-Load Losses (W)	PnL	P_{nl}	1636.7

Table 31: Contd.,			
Wattful Current (A) or core loss current	Iw	I_w or I_c	1.369

Various values of Limits in the design of motor are listed in the following table.

Table 32: Limiting Flux Density Values of Motor Components

Position	Typical Flux Density Range (Ref. –Say Author)	Maximum Flux Density (Ref –Lipo Author)
Air gap B_g	0.65 -0.82 T (average)	
Stator yoke	1.1 -1.45 T (peak)	1.7 T
Stator teeth	1.4 -1.7 T	2.1 T
Rotor yoke	1.2 T	1.7 T
Rotor teeth	1.5-1.8 T	2.2 T

XXVI. ELECTRICAL AND MAGNETIC PARAMETERS

The effect of change in magnetic flux due to the presence of slots on the laminations of stator and rotor empirical factors K_{c1}, K_{c2}, $\tau_{sg1} =$, $\tau_{sg1} =$ are evaluated and

Where K_{c1} = Gap contraction factor for stator

$$K_{c1} = \frac{\tau_{sg1}}{\tau_{sg1} - b_{01}\, K_{01}} \quad (31) \quad \& \quad \tau_{sg1} = \frac{\pi\, D}{S_1} \qquad (32)$$

The values of ratio of stator slot opening and air gap for stator and rotor are found out. Using the values of Slot pitch for stator and rotor the values of gap contraction for stator (32) and rotor (34) are calculated. Carter’s coefficients both for Stator and Rotor are found out from the interpolations.

Carter coefficients for stator and rotor are obtained from the ratios: a) Stator slot width to air gap length ratio and b) Rotor slot width to air gap length ratio

$$K_{c2} = \frac{\tau_{sg2}}{\tau_{sg2} - b_{02}\, K_{02}} \quad (33) \quad \& \quad \tau_{sg2} = \frac{\pi\,(D - 2lg)}{S_2} \qquad (34)$$

and K_{01} & K_{02} are constants or Carter coefficients for rotor and stator respectively

K_{c1} and k_{c2} are gap contraction factor for stator and rotor respectively

l_g' = overall gap contraction factor = K_{c1} x k_{c2} (35)

Effective air gap length $l_g' = l_g\, K_{c1}\, K_{c2}$ (36)

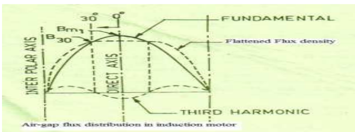

Figure 1

XXVII. MMF REQUIRED IN AIR GAP AT_δ

$$H = \frac{1}{\mu_0} B \text{ AT/m} \qquad (37)$$

$$H = \frac{1}{\mu_0} B_{30^0} l_g' \quad (38)$$

$$H = \frac{1}{\mu_0} B_{30^0}\, l_g\, K_{c1}\, K_{c2} \quad (39)$$

XXVIII. FLUX DENSITY DISTRIBUTION

Flux density at 30^0 from direct axis

= flux density at 60^0 from inter-polar axis

$So\ B_{30}^0 = B_{60}^0 = B_{m1} \text{Cos } 30^0$

$$= \frac{\pi}{2} B'' \frac{\sqrt{3}}{2} = 1.36\ B'' \quad (40)$$

For all practical purposes this value is modified to

$$B_{30}^0 = 1.35\ B'' \quad (41)$$

XXIX. STEP 3 OF PART IV

For the calculation of Ampere-turns for Air gap, Stator tooth, Stator core, Rotor tooth, and Total No-load AT, Magnetizing current, No -Load PF.

Table 33: Carters' and AT/m Coefficients

Interpolated Values Of Caters' Coefficients			
Carter's coeff - Stator	k01	k_{01}	0.600
Carter's coeff - Rotor	k02	k_{02}	0.395
Stator Core AT/m			446.7
Teeth AT/m			986.0

XXX. STEP 4 AND STEP 5 OF PART IV

In these two steps, the flux densities at locations of stator yoke, stator tooth, rotor tooth and rotor core (yoke) and air gap are calculate first. Then corresponding Ampere turns/ Unit length of magnetic flux path (AT/m) are calculated. With flux path length known, the values of AT for all locations and their sum are calculated described in steps of a) to f).

Table 34: Length of Path and Ampere Turns at Locations -Formulas

S .No	Part	Length of Path	Flux Density	at (AT/m)	$AT_{pol\ e\text{-}Pair}$
1	Stator Yoke	l_y	B_y	at_y	AT_y
2	Stator Tooth	$2h_{t1}$	$B_{t\frac{1}{3}h_{t1}}$	at_{2ht1}	AT_{2ht1}
3	Air Gap	$2l_g'$	$B_{30}0$	$at_{2g'}$	$AT_{2g'}$
4	Rotor Tooth	$2h_{t2}$	$B_{t\frac{1}{3}h_{t2}}$	at_{2ht2}	AT_{2ht2}
5	Rotor Yoke	l_{ry}	B_{ry}	at_{ry}	AT_{ry}

$$AT_{pole\text{-}pair} = AT_{30} = \sum$$

Magnetising mmf is calculated with the help of magnetising curve and physical dimensions of stator teeth, stator core, rotor teeth, rotor core and air gap.

- Length of path for air gap ($2l_g'$), flux density for air gap $B_{30}{}^0$, at 30(AT/m) -at $_{2\delta}$ and $AT_{2\delta'}$ for one pole are calculated
- Length of path for stator teeth ($2h_{t1}$), flux density for stator teeth, $B_{t\frac{1}{3}h_{t1}}$ at_{2ht1} at (AT/m) and AT for stator teeth are calculated
- Length of path for stator core or yoke (l_y), flux density for stator core (B_y), at (AT/m) at_y and AT_y for stator core a (AT_{2ht1}) are calculated
- Length of path for rotor teeth ($2h_{t2}$), flux density for rotor teeth, at (AT/m) and AT for rotor teeth are
- calculated
- Length of path for rotor core or yoke (l_{ry}), flux density for stator core (B_{ry}), at (AT/m) at_{ry} and AT_{ry} for stator core a (AT_{ry}) are calculated

Table 35: Length of Path and Ampere Turns at Locations -Values

Used for	MATLAB variable	Variable used in Equations	Value
Core	ATSC		38.5
Teeth	ATST		42.4
TOTAL	**ATS**		**80.9**
ROTOR AT			
Core	ATRC		17.8
Teeth	ATRT		5.5
Table XXXV: Contd.,			
TOTAL	**ATR**		**23.3**
TOTAL AT			
Stator	ATS		80.9
Rotor	ATR		23.3
Airgap			496.0
TOTAL	**ATT**		**600.2**

XXXI. STEP 1 OF PART V – NO LOAD MOTOR PERFORMANCE

Determination of Core Loss Current (I_c)

Total iron losses P_i = Iron loss in teeth + Iron loss in yoke

Active/ Wattful component of no load /Phase current $$I_c = \frac{P_i}{3\,V_{ph1}} \quad (42)$$

The weight of iron in the stator is found and iron losses are calculated from material data sheets of losses in W/kg depending on flux density and frequency. Iron loss in rotor is negligible because of low frequency and this loss is generally accounted as part of stray load loss or additional loss.

Magnetising Current

$$I_m = AT_{30}\frac{P}{2}\frac{1}{1.17N_{ph1}\,K_{d1}} \tag{43}$$

Calculation of No Load Current (I_o)

To solve the magnetic circuit of motor, the no load current has to be determined. Thus one has to estimate the magnetizing component (Im) and then core loss component (I_c) of current.

No load current I_0

$$I_0 = \sqrt{I_c^2 + I_m^2} \tag{44}$$

No load power factor $\cos\varphi_0 = \frac{I_c}{I_0}$ (45)

Table 36: Performance of Motor at No Load

No-Load Current (A)				Eq.
Core loss	Iw	I_w	1.37	(42)
Magnetising	Im	I_m	8.95	(43)
No Load	Io	Io	9.06	(44)
Power factor	pf	pf	0.151	(45)
Ratio of No Load Current to Phase Current				
	I_0/I_{ph} ratio	I_O/I_{ph} ratio	0.285	

The six impedances are stator resistance R_1, stator leakage reactance X_{01}, magnetizing reactance X_{0m}, core loss Resistance R_m, rotor leakage reactance X_{02}, and rotor resistance R_2.

XXXII. STEP 3 OF PART V - SHORT CIRCUIT RESISTANCES --MOTOR PERFORMANCE

MATLAB program is structured such that there is a scope for introducing a loop which can take care of different geometries of slots after the dimensional details of slot geometries are input for carrying out the optimisation. Generally this way of achieving motor optimisation is considered as the difficult strategy and optimisation is not done from this aspect.

Specific Slot Permeability

Specific performance is evaluated based on

Specific permeability for a tapered stator slot is

$$\lambda_{sp,s} = \mu_0\left[\frac{2h_1}{(3\,W_2+W_{ss})} + \frac{2h_2}{(W_1+W_2)} + \frac{h_3}{(W_1+W_0)} + \frac{h_4}{W_0}\right] \tag{46}$$

Specific permeability for a tapered rotor slot is

$$\lambda_{sp,r} = \mu_0\left[\frac{h_1}{3w} + \frac{h_2}{w} + \frac{2\,h_3}{(w+w_0)} + \frac{h_4}{w_0}\right] \tag{47}$$

Total Specific Slot Permeability

λ_s = (Specific slot permeability for stator slot+ specific slot permeability for rotor slot).

$= \lambda_{sp,s} + \lambda_{sp,r}$ (48)

Slot Leakage Reactance

$$Xs = \frac{8\,\pi\, f\, N_{ph}^2\, L\, \lambda_s}{P\, qs} \quad (49)$$

Overhang Leakage Reactance

$$X_0 = \frac{0.64\,\pi\, f\, N_{ph}^2\, \mu_0 \tau^2}{\pi\, p\, q_s y_{ss}} \quad (50)$$

Here, $\tau = \frac{\pi\, D}{P}$ and $y_{ss} = \frac{\pi\, D}{S_s}$

Zigzag Leakage Reactance

Core reactance $X_m = \frac{V_{ph}}{Im}$ (51)

$$X_z = \frac{5}{6}\,\frac{X_m}{9}\,[\frac{1}{q_s^2} + \frac{1}{q_r^2}] \quad (52)$$

Here, rotor slot per pole per phase, $q_r = \frac{Sr}{3\,p}$

Total Leakage Reactance per Phase

$X = X_l = (X_s + X_o + X_z)$. (53)

$Z = \sqrt{R^2 + X^2}$ (54)

Short Circuit Current

$I_{sc} = \frac{V_{ph}}{Z}$ (55)

$Pf_{sc} = \frac{R}{Z}$ (56)

Overload capacity $= \frac{I_{sc}}{I_{ph}}$ (57)

Table 37: Total Reactance (Short Circuit Resistance)

Total Reactance Equation				
Slot	(47)	X_s	Xs	0.925
Overhang	(48)	X_0	X0	0.909
Zig-Zag	(49)	X_z	Xz	0.648
SHORT CIRCUIT Resistance		R	R	0.67
Total leakage REACTANCE (X)	(51)	X	X	2.481

Z	(52)	Z	Z	2.57
I_{sc}	(53)	I_{sc}	Isc	155.0
pf	(54)	pf_{sc}	pfsc	0.260
(I_{sc} / I_{ph}) or (I_{sc} /I_{FL})	(55)	Iratio	I_{ratio}	4.879

XXXIII. STEP 4 OF PART V LOAD LOSSES

Load losses are the losses at the operating load losses will finally evaluate the performance of the motor. For some motors which operate at different loads performance at different loads also are evaluated.

Load loss= stator copper loss + rotor copper loss + No load

Table 38: Losses of Motor at Operating Load

No Load Losses	**PnL**	$\mathbf{P_{nL}}$	**961.9**
Stator copper losses	Pcus	P_{cus}	769.1
Rotor copper losses	Pcur	P_{cur}	1636.7
Total Losses	**Pt**	$\mathbf{P_{total}}$	**3367.7**

XXXIV. STEP 5 OF PART V - TOTAL WEIGHT AND KG/KW

Estimation of weights of all the components and total weight of motor of a particular capacity of motor is essential where optimization leading to a lighter motor for the given capacity motor is a requirement. Total weight of all the main components and specific power is calculated.

Table 39: Weights of Motor Components

Total Weight Of The Components			
Stator copper	wcus	w_{cus}	27.4
Stator teeth	wt	w_t	19.2
Stator core	wsi	w_{si}	46.8
Rotor core	wri	w_{ri}	32.1
Rotor bars	wcur	w_{cur}	7.3
End rings	wcue	w_{cue}	2.2
Total	wtotal	w_{total}	136.5
Kg/KW	kgpkw	w_{total}/KW	4.55

XXXIV. STEP 6 OF PART V –MOTOR PERFORMANCE LOAD

In this step motor performance parameters namely efficiency, Slip at FL, Starting torque, Maximum Output (KW) and Temperature rise are estimated.

η = output / (output+ No load loss + Load loss)

R_{inp} = Input power to Rotor = KW of motor + Rotor copper losses + Losses due to friction and windage

Slip at FL = Rotor Copper losses / Input power to Rotor

Table 40: Motor Performance Parameters

Efficiency %	EFF	η	89.91
Slip at FL %	SFL	S_{FL}	2.475
Starting Torque	Tst	T_{st}	0.816
Maximum Output	Pmax	P_{max}	69.2

XXXV. STEP 7 OF PART VAPPROXIMATE TEMPERATURE RISE ESTIMATION

Highly approximate method of estimation of temperature rise of stator frame has been mentioned in this step. In this evaluation end caps are considered as part of the frame and the temperature corresponds to broad average temperature rise of the frame which includes end caps on both sides of TEFC motor.

For all the motors efficiency (η) of fan is considered as 0.5

Inner area of stator bore = A_{inner} =(π x D x L*2.5 + (2.* π *(D+50)*0.04)/1e06

Peripheral velocity = v = π x D x ns x efficiency of fan

Effective area factor = A_{factor} = (1 + 0.1 v)

Effective area = A_{eff_inner} = A_{factor} x A_{inner}

Outer stator area = A_{outer} = π x D_{out} x L

Total dissipating area = Acool_total = A_{eff_inner} + A_{outer}

Tr = 0.03 *Pst/Acool_total;

Table 41: Approximate Temperature Rise

Inner area of Stator Bore m^2	Peripheral Velocity m/sec	Effective Area Factor m^2	Effective Area m^2	Outer Stator Area m^2	Total Area m^2	Temperature Rise of Frame Surface
0.346	8.37	1.837	0.926	0.234	1.16	59.45

XXXVI OPTIMISATION OF MOTOR

For optimization of motor current density values, slot height to width and slot fill factors are varied for round conductors and current density values, height to thickness of bar and height to width of slot are varied. The results are presented in the following tables. J and Thick refer to current density and insulation thickness in the following tables.

Table 42: Optimization of Motor Using Rod Conductors

Rod Conductors are Used						
WXH	Bt_{max}	T_r	D_0	η	Kgp Kw	I0byI
Rods are 3.2 mm dia x 0.5 thick and J is 3.5 A/mm²						
7.0X21	1.31	45.7	320	91.67	4.02	0.30
6.3X19	1.21	44.7	320	91.78	3.99	0.30
6.1X24	1.15	46.3	330	91.58	4.18	0.30
5.4X22	1.09	45.2	320	91.73	4.12	0.30
Rods are 3.0 mm dia x 0.5 thick and J is 3.5 A/mm²						
6.8X20	1.28	48.4	320	91.39	3.90	0.30
6.1X18	1.19	47.4	320	91.49	3.87	0.30
5.9X24	1.13	48.9	330	91.30	4.06	0.30
5.3X21	1.07	47.9	320	91.44	3.99	0.30
Rods are 2.8 mm dia x 0.5 thick and J is 3.5 A/mm²						
6.7X20	1.26	51.1	320	91.11	3.81	0.30
6.0X18	1.18	50.1	310	91.24	3.76	0.30
5.8X23	1.12	51.6	330	91.02	3.96	0.30
5.2X21	1.06	50.7	320	91.15	3.90	0.30

	%Max. Eff.	Min. Kg /KW	Min Temp-Rise	Min IOIr ratio
	91.78	3.76	44.70	0.30
Variant	**2**	**0**	**2**	**10**

Table 43: Optimization of Motor Using Bar Conductors

Bar conductors are used						
WXH	Bt_{max}	T_r	D_0	η	Kgp Kw	I0byI
Bar C/s is 12 x 6.5 Current Density 3.5 A/mm2						
8.7X48	1.39	55.6	370	90.47	4.70	0.31
8.7X48	1.39	55.6	370	90.47	4.70	0.31
Bar C/s is 1.8 x 5.0 and Current Density is 3.5 A/mm2						
10.2X40	1.85	53.4	360	90.74	4.40	0.39
10.2X40	1.85	53.4	360	90.74	4.40	0.39
Bar C/s is 1.2 x 6.0 and Current Density is 4.0 A/mm2						
8.7X46	1.41	56.6	370	90.37	4.56	0.31
8.7X46	1.41	56.6	370	90.37	4.56	0.31
Bar C/s is 1.8x 4.5 and Current Density is 4.0 A/mm2						
10.2X38	1.89	54.7	350	90.63	4.22	0.41
10.2X38	1.89	54.7	350	90.63	4.22	0.41
Bar C/s is 1.2x 5.5 and Current Density is 4.5 A/mm2						
8.7X43	1.43	57.9	360	90.27	4.41	0.31
8.7X43	1.43	57.9	360	90.27	4.41	0.31
Bar C/s is 1.8x 4.0 and Current Density is 4.5 A/mm2						
10.2x36	1.93	56.6	350	90.44	4.07	0.42
10.2x36	1.93	56.6	350	90.44	4.07	0.42

	Max. Eff. %	Min. Kg /KW	Min Δθ	Min IOIr ratio
	90.74	4.07	53.42	0.31
Variant	**4**	**0**	**4**	**10**

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APPENDICES

```
%Annexure
MATLAB Program for Traditional Design and
% Optimization of Performance of 30 KW SCIM Motor
f2=fopen('motor_30KW_m','w');
%<--Step I of part I ---Basic Dimensions of Motor->
```

```
optim=1;cond_type=1;slot_fill_factor=0.4;

D=213; L=207;KW=30.0;f=50;P=4;%Specification/lnput Data------>

Ns=120*f/P;ns=Ns/60;Kw=0.955;insH=6;insS=0.5; %Initial Values

KWinp=30;

% Step 2 of Part I - Electro magnetic parameters of motor

V=398.37;ki=0.96; Tstrip=1.50 ;

insW=3.4;Hw=4;HL=1;insH=6;ki=0.92;Bc=1.35;Vph=V;%Initial Values

Zr=1;kwr=1;cdb=6;Tb=6;cde=6;dd=0.05;Brc=1.35;

sn=0;M1=0;M2=0;M3=0;M4=0;EFFmax=90;minKgPkw=9;minTr=75 ;minIObyI=5;

Vph=V;  P=4; spp=4;Zsw=3;

% Step 3 and step 4 are for checking the limits like bearings and frames

%Initial Values -Standard Curves/Tables for%Data---->

SD=[0.1  0.15 0.2 0.3 0.4 0.5 0.75 1];

SCDSW=[4 3.8 3.6 3.5 3.5 3.5 3.5 3.5];

B=[0.8 1.2 1.6 2 2.4]; WpKg=[7 15 24 34 50];

%Step 6 of Part I of traditional design

SKW=[1 2 5 10 20 50 100 500];

SBav=[0.35 0.38 0.42 0.46 0.48 0.50 0.51 0.53];

Sq=[16e3 19e3 23e3 25e3 26e3 29e3 31e3 33e3];

SKWa=[5 10 20 50 100 200 500];

SPF4P=[0.85 0.86 0.88 0.9 0.91 .92 .93];%Table: for 1500RPM

SEFF4P=[.85 .87 .88 .9 .91 .93 .94];%Table for 1500RPM

SD=[0.1 0.15 0.2 0.3 0.4 0.5 0.75 1];

SCDSW=[4 3.8 3.6 3.5 3.5 3.5 3.5 3.5];

%-------------BH Curve for--0.5mm,LOHYS Quality--------->

BBone= [ .1 .2 .3 .4 .5 .6 .7 .8 .9 1 ];

BBtwo= [1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2];

Hone= [50 65 70 80 90 100 110 120 150 180] ;

Htwo= [220 295 400 580 1000 1400 5000 8900 15000 24000];
```

```
BB= [BBone BBtwo];
H = [Hone Htwo];
%-------Carters Coefft for Air Gap--->
Ratio=[0 1 2 3 4 5 6 7 8 9 10 11 12];
CC=  [0 .18 .33 .45 .53 .6 .66 .71 .75 .79 .82 .86 .89] ;
CC1= [0 .14 .27 .37 .44 .5 .54 .58 .62 .65 .68 .69 .7];
%Step 5 of Part I of traditional design
pf=interp1(SKWa,SPF4P,KW, 'spline');
eff_data=interp1(SKWa,SEFF4P,KW, 'spline');
Bav=interp1(SKW,SBav,KW, 'spline');
q=interp1(SKW,Sq,KW, 'spline');
Iph=KWinp*1e3/(3*Vph*pf);
CO=11*Kw*Bav*q*eff_data*pf*1e-3; % Equation (4);
KWinp=KW/eff_data;
Ls=L;Li= ki*Ls; PP=pi*D/P; LbyPP=L/PP
% if LbyPP <0.8 || LbyPP >2 continue; end;
v=pi*D*ns/1000
if v >30 continue;end;
FI=pi*D/P*L*Bav/1e6 ;
Tphi=Vph/(4.44*f*FI*Kw);S=spp*P*3;
CDSW_int=3.5; CDSW_end=4.5;CDSW_ave=(CDSW_int+ CDSW_end)/2;
if(cond_type==1) % Circular conductors
L2_int=3.0;L2_end=4.0;L2_incre=1;% loop two is variation of slot height and slot width ratio
L3_int=0.4;L3_end=0.5;L3_incre=0.1;% loop three is varying slot_fill factor
end;
if(cond_type==2)% Bar conductors
L2_int=1.25;  L2_end=1.75;  L2_incre=0.5;% Bar thickness
L3_int=2;L3_end=3;L3_incre=1; % Bar height to width ratio
Tstrip=(L2_int+L2_end)/2;
```

```
end;
L2_ave=(L2_int+L2_end)/2;
L3_ave=(L3_int+L3_end)/2;
if optim==0  % Fixed values of current density and slot dimensions
CDSW_int=CDSW_end;L2_int=L2_end;
L3_int=L3_end;
end;
for CDSW =CDSW_int:0.5:CDSW_end;
As1=Iph/CDSW;
if optim==0 As1=Iph/CDSW_ave;end;
SPitch=pi*D/S;
% if SPitch <18 || SPitch>=25 continue; end;
Zphi=2*Tphi; sph=S/3; Zsl=Zphi/sph;Zs=ceil (Zsl); Tph=Zs*sph/2;
slots_per_phase=sph;cond_per_phase=Zphi;
cond_per_slot= (cond_per_phase/slots_per_phase);
FI=Vph/(4.44*f*Tph*Kw);
if optim==0 L2_incre=1;L3_incre=1;end;
for L2_value =L2_int:L2_incre:L2_end;
if(cond_type==2)
Tstrip=L2_ave;
if optim==1 Tstrip=L2_value;end;
Hstrip1=As1/L2_value;
Hstrip=ceil(Hstrip1*2)/2 ;
WbyT=Hstrip/Tstrip
% if WbyT <2.5 || WbyT >=3.5 continue; end;
As=0.967*Hstrip*Tstrip;
end;
for L3_value=L3_int:L3_incre:L3_end;
if(cond_type==2)
```

```
zsw=L3_value;
Ws=(Zsw*(Tstrip+insS)+insW);
Zsh=Zs/Zsw;
Hs=(Zsh*(Hstrip+insS)+Hw+HL+insH+2);% Hw is height of wedge and 2 is clearance
end;
if(cond_type==1)
As=Iph/CDSW;
cond_dia = (As*4.0/pi)^0.5;
HtbyWd=L2_ave;
slot_fill_factor=L3_ave;
if(optim==1) HtbyWd=L2_value;slot_fill_factor=L3_value;end;
slot_area= (cond_dia+2*insS) *cond_per_slot/slot_fill_factor;
Slot_wide =(slot_area /HtbyWd)^0.5;Slot_hight= Slot_wide*HtbyWd;
cond_along_width=(Slot_wide/(cond_dia+2*insS));
cond_along_hight=(Slot_hight/(cond_dia+2*insS));
Ws=Slot_wide;Hs=Slot_hight;
Zsh=cond_along_hight;Zsw=cond_along_width;
Hstrip=cond_dia+2.0*insS;
end;
%Step 3 of Part II
D13=D+2/3*Hs;
sp13=pi*D13/S;
Wt13=sp13-Ws;
B13=FI*P*1e6/(Li*Wt13*S);% Equation 15
Btmax=1.5*B13;
Lmt=(2*L+2.3*PP+240)/1000; % Equation 16
Rph=0.021*Lmt*Tph/As;% Equation 17
Pcus=3*Iph^2*Rph; Wcus=Lmt*Tph*3*As*8.9e-3; Flc=FI/2;
Ac=Flc*1e6/Bc;Hc=Ac/Li; D01=D+2*(Hs+Hc); DO=ceil(D01/10)*10;
```

```
Hc=(DO-D)/2-Hs;

% Table XXIII Iron losses and weight of stator

PitpKg=interp1(B,WpKg,Btmax, 'spline');

PicpKg=interp1(B,WpKg,Bc, 'spline');

Wt=Li*Wt13*S*Hs*7.8e-6; %Weight of teeth

Dmcs=D+2*Hs+Hc; Wc=Ac*pi*Dmcs*7.8e-6; %Weight of core

Pit=PitpKg*Wt;Pic=PicpKg*Wc;

%----------------------ROTOR---------------------->

Zr=1;kwr=1;cdb=6;;cde=6;dd=50;Brc=1.35; %Initial Values

kws=Kw;Ss=S;Lg1=0.2+2*sqrt(D*L/1e6);

Lg=ceil(Lg1*100)/100;

% Rotor slot numbers that need to be avoided for preventing rotor locking

d1=Ss-3*P;d2=Ss-P;d3=Ss-2*P; d4=Ss-5*P;d5=Ss-1;d6=Ss-2;d7=Ss-7;d8=Ss-8;

n_lams=1;

LG= [0.8 0.8 0.8 0.8];WSS0=[4.0 4.0 4.0 4.0];WSR0=[2.0 2.0 2.0 2.0];

H2=[1.6 1.6 1.6 1.6];H2R=[0 0 0 0]; H3R=[0 0 0 0]; H4R= [0.5 0.5 0.5 0.5];

for L4 =1:n_lams

Lg=LG(L4);% Lg=LG(L4);

Dr=D-2*Lg;Sr=39;  Tb=6.0;

%Step 1 and Step 2 of Part III

sp2=pi*Dr/Sr; Ir=0.85*Iph;

%Step 3 of Part III

Ib=Ir*kws*Ss*Zs/(kwr*Sr*Zr);%Equation 19

Abi=Ib/cdb; Wb=ceil(Abi/Tb);

Ab=Tb*Wb*0.98;Wsr=Tb+0.5;Hsr=Wb+0.5;Lb=L+50;Rb=0.021*Lb/1e3/Ab;

Dme=Dr-dd; Pcub=Ib^2*Rb*Sr; Ie=Ib*Sr/P/pi; Ae=Ie/cde;

Lme=pi*Dme/1000;Re=0.021*Lme/Ae;

Pcue=2*Ie^2*Re;Pcur=Pcub+Pcue;Rr=Pcur/(3*Ir^2);

Dr13=Dr-2*2/3*Hsr;spr13=pi*Dr13/Sr
```

```
Wtr13=spr13-Wsr;Atr=Wtr13*Li*Sr/P;Brt=FI*1e6/Atr;
Brtmax=Brt*1.5;Ac=FI*1e6/2/Brc;dcr=Ac/Li;
Pfw=0.01*KW*1e3;PnL=Pit+Pic+Pfw;Iw=PnL/3/V;
Wcur=Lb*Sr*Ab*8.9e-6;Wcue=Lme*2*Ae*8.9e-3;
%(4)<--AmpTurns and Magnetizing-Current--Part IV-->
Wsso=WSS0(L4);Wsro=WSR0(L4);  %Initial Values
atsc=interp1(BB,H,Bc, 'spline');
%Step 4 and Step 5 of Part IV
Dcav=D+2*Hs+Hc;ATSC=pi*Dcav/P/3*atsc/1e3;
Bt30=B13*1.36;% Equation (41) for stator
atst=interp1(BB,H,Bt30, 'spline');
ATST=atst*Hs/1000;
ATS=ATSC+ATST %Amp turns for tooth and core
rat1=Wsso/Lg
k01=interp1(Ratio,CC,rat1, 'spline');
kgs=SPitch/(SPitch-Wsso*k01); %Equation 32
rat2=Wsro/Lg;
k02=interp1(Ratio,CC,rat2, 'spline'); %Equation 48
spro=pi*Dr/Sr; %Equation 35
kgr=spro/(spro-Wsro*k02); kg=kgs*kgr; Lgd=Lg*kg;
% rat3=bvd/Lg; kv=interp1(Ratio,CC1,rat3, 'spline');
% if rat3 >=12 kv=0.7;end;
Ld=L;Aag=pi*D/P*Ld;Bg=FI*1e6/Aag;
B30d=1.36*Bg;
ATg= 0.796*B30d*Lgd*1e3
Btr30=Brt*1.36 % Equation 41 for rotor
atrt=interp1(BB,H,Btr30, 'spline')  % at of rotor teeth
ATRT=atrt*Hsr/1e3;
Dcrav=Dr-2*Hsr-dcr;
```

```
atrc=interp1(BB,H,Brc, 'spline')

ATRC=pi*Dcrav/1e3/P/3*atrc;

ATR=ATRC+ATRT % AT of rotor core and rotor teeth

ATT=ATS+ATR+ATg;  % Step 1 of part V

Im=P/2*ATT/(1.17*Kw*Tph); %Equation 43

I0=sqrt(Iw^2+Im^2);%Equation 44

Pf0=Iw/I0; I0byI=I0/Iph;%Equation 45

% (5) <--Step 3 of part 5--Short-Circuit-Current--->');

h2=H2(L4);h2r=H2R(L4);h3r=H3R(L4);h4r=H4R(L4); ks=1; %Initial Values

if(cond_type==1) Hstrip=cond_dia+2*insS;end;

h1=Zsh*(Hstrip+insS);h3=Hw;h4=HL;bs=Ws;

bO=Wsso;Lmdss=h1/3/bs +h2/bs +2*h3/(bs+bO) +h4/bO;

h1r=Wb; br=Wsr; %Equation 45

br0=Wsro;Lmdsr=h1r/3/br+h2r/br+2*h3r/(br+br0)+h4r/br0;

Lmddsr=Kw^2*S/Sr*Lmdsr; ssp=Lmdss+Lmddsr; gd=S/P/3;

p=P/2;Xs=15.8*f*L*ssp*Tph^2/(p*gd)*1e-9 %Equation 47

L0Lmd0=ks*PP^2/pi/SPitch/1000;

X0=15.8*f*L0Lmd0*Tph^2/(p*gd)*1e-6 %Equation 48

gs=S/P;gr=Sr/P;Xm=Vph/Im %Equation 49

Xz=5/6*Xm*(1/gs^2+1/gr^2) %Equation 50

X=Xs+X0+Xz; R=Rph+Rr;%Equation 51

Z=sqrt(R^2+X^2); Isc=Vph/Z;

pfsc=R/Z; RAT=Isc/Iph;%Equations 52,53

%(6)<--------Performance--------------->');

Pt=PnL+Pcus+Pcur; %Table XXXVII

eff=KW/(KW+Pt/1000)*100

if optim==1 & eff<88.8 continue;end;

Rinp=KW*1000+Pfw+Pcur;

SFL=Pcur/Rinp*100; Tst=(Isc/Ir)^2*SFL/100;
```

```
Pmax=3*Vph*(Isc-I0)/2/(1+pfsc)*1e-3;

Acool1=(pi*D*(L*2.5)+2*pi*(D+50)*0.04)/1e6;

Acoo12=Acool1*(1+0.1*v);

Acoo13=pi*DO*L/1e6;

AcoolT=Acoo12+Acoo13;

Pst=Pcus+Pit+Pic;

Tr=0.03*Pst/AcoolT;

% if optim==1 & Tr>56 continue;end;

Ars=Wsr*Hsr*Sr;Dri=Dcrav-dcr;

Wri=(pi*(Dr^2-Dri^2)/4-Ars)*L*7.8e-6;

Wtot=1.01*(Wcus+Wt+Wc+Wri+Wcur+Wcue);KgPkw=Wtot/KW;

if optim==1 & KgPkw>6.1 continue;end;

%-----End of TRaditional design Program---->

if optim==0

fprintf(f2, 'Design of 30KW,440V,50HZ,3-Ph SCIM\n');

fprintf(f2, '\nInput Data:');

fprintf(f2, '\n-----------');

fprintf(f2, '\nParamter                    VALUES');

fprintf(f2, '\n--');

fprintf(f2, '\nRating(KW)   %5.1f',KW);

fprintf(f2, '\nVolts%5.0f',V);

fprintf(f2, '\nPoles%5.0f',P);

fprintf(f2, '\nHz    %5.0f',f);

fprintf(f2, '\nInterpolated values from curves: Bav=%5.3f,q=%5.0f',Bav,q);

fprintf(f2, 'eff=%7.2f,pf=%5.3f',eff,pf);

fprintf(f2, '\nOutput Results:');

fprintf(f2, '\n==============');

fprintf(f2, '\nParamter VALUES');

fprintf(f2, '\n-------                        -------');
```

```
fprintf(f2, '\nOutput Coefft(CO)%6.2f' ,CO);
fprintf(f2, '\nSync.Speed(rps) %5.2f',ns) ;
fprintf(f2, '\nGross Length(mm) %5.1f',L);
fprintf(f2, '\nNet iron Length(mm)   % 5.1f',Li) ;
fprintf(f2, '\nStator Inner Dia(mm)  %5.1f',D);
fprintf(f2, '\nPeriphoral Speed(m/s) %5.2f (Max. Limit: 30)',v) ;
fprintf(f2, '\nPole-Pitch(mm)%5.1f',PP);
fprintf(f2, '\nL to PP ratio %6.4f (Around 1 >good)',LbyPP) ;
fprintf(f2, '\nSlots %5.0f',S);
fprintf(f2, '\nSlot-Pitch(mm)%6.3f(Limit:18to25mm)',SPitch);
fprintf(f2, '\nCond/Slot %5.0f',Zs);
fprintf(f2, '\nTurns/Ph%5.0f',Tph);
fprintf(f2, '\nFlux/Pole(Wb)%6.5f',FI);
fprintf(f2, '\nPhase Current (A) %5.2f',Iph);
if cond_type==2 fprintf(f2, '\nBare Strip (w*t)mm      %5.2fX%4.2f',Hstrip,Tstrip);
fprintf(f2,'\nW and T Ratio %5.2f(Limit:2.5to3.5)',WbyT);
end;
if cond_type==1 fprintf(f2, '\nBare dia and insulation mm        %5.2fX%4.2f',cond_dia,insS);
fprintf(f2,'\nW and T Ratio %5.2f(Limit:2.5to3.5)',WbyT);
end;
fprintf(f2, '\nArea of CS cond(mm^2) %7.3f',As);
fprintf(f2, '\nCt.density(A/mm^2)    %7.3f',CDSW);
fprintf(f2, '\n values of W/KgTeeth=%5.2f Core=%5.2f',PitpKg, PicpKg);
fprintf(f2, '\n Strips (width*depth-wise) %4.0f  X%2.0f',Zsw,Zsh);
fprintf(f2, '\nSlot-Width (mm) %6.1f',Ws);
fprintf(f2, '\nSlot-Height(mm)Total  %6.1f',Hs) ;
fprintf(f2, '\n d(l/3),SP(l/3),Wt(l/3)(m)%6.4f,%6.4f,%6.4f',D13,sp13,Wt13);
fprintf(f2, '\nSt-Tooth-Flux-Dens(1/3) %6.4f',B13);
fprintf(f2, '\nSt-Tooth-Flux-Density -Max(T)     %6.4f(Limit:1.6to1.8)',B13*1.5);
```

```
fprintf(f2, '\nLength of mean-turn (m)%6.3f' ,Lmt);
fprintf(f2, '\nResistance/Ph (ohm)    % 6.4f',Rph) ;
fprintf(f2, '\ndepth of St.Core(mm)  %6.2f',Hc);
fprintf(f2, '\nOuter Dia of St.Core(mm) %6.1f' ,DO);
fprintf(f2, '\nSt.Cu.Loss(W) %6.1f',Pcus);
fprintf(f2, '\nWt of St-Teeth+Core(Kg)= %6.2f+%6.2f=%6.2f',Wt,Wc,Wt+Wc);
fprintf(f2, '\nIron Loss=Teeth+Core(W)= %5.1f+%5.1f= %5.1f',Pit,Pic,Pit+Pic);
fprintf(f2, '\n--Part III---ROTOR- Design-------->');
fprintf(f2, '\nLength of Air-Gap(mm)%6.4f' ,Lg);
fprintf(f2, '\n Dia of Rotor(mm) )     % 6.1f',Dr);
fprintf(f2, '\nNo of Slots Should  NE to:%2.0f,%2.0f,%2.0f, % 2.0f, %2.0f',d1,d2,d3,d4);
fprintf(f2, '\nShould NE to:%2.0f,%2.0f,%2.0f,%2.0f,%2.0f',d5,d6,d7,d8);
fprintf(f2, '\nNo of Rotor Slots Selected %3.0f',Sr);
fprintf(f2, '\nRotor Slot-Pitch(mm) %6.4f',sp2);
fprintf(f2, '\nEquivalent Rotor Ct(A) %6.2f',Ir);
fprintf(f2, '\nRotor bar Ct(A) %6.1f',Ib);
fprintf(f2, '\nRotor bar CS(mm^2)   %6.4f',Ab);
fprintf(f2, '\nBar (w*t)mm %5.1fX%4.1f',Wb,Tb);
fprintf(f2, '\nRotor Slot (w*h)mm     %5.1fX%4.1f',Wsr,Hsr);
fprintf(f2, '\nLength of Bar (m) %5.3f',Lb);
fprintf(f2, '\nResistance/bar(m.ohm) %6.4f',Rb*1e3);
fprintf(f2, '\nLosses in Rot.Bars (W) %6.1f',Pcub);
fprintf(f2, '\nEnd ring Ct(A) %6.1f',Ie);
fprintf(f2, '\nArea of end ring (mm^2) %6.1f',Ae);
fprintf(f2, '\nResistance of end ring(m.ohm)  %6.4f',Re*1e3);
fprintf(f2, '\nRot-Cu- Loss=Bars+End.rings(W)=%5.1f+%5.1f=%5.1f',Pcub,Pcue, Pcur);
fprintf(f2, '\nEquivalent Rotor res (Ohm) %6.3f' ,Rr);
fprintf(f2, '\nRotor(1/3)Slot-Pitch(mm) %6.2f' ,spr13);
fprintf(f2, '\nRotor(1/3)tooth width(mm) %6.2f' ,Wtr13);
```

```
fprintf (f2, '\nRt-Tooth-Flux-Dens (1/3) (T) % 6.4f', Brt) ;
fprintf(f2, '\nRt-Tooth-Flux-Dens-Max(T)    %6.4f(Limit:1.2to1.5)' ,Brt*1.5);
fprintf(f2, '\nDepth of Rotor core (mm) % 5.2f',dcr) ;
fprintf(f2, '\n-------No-Load-Losses---------------->');
fprintf(f2, '\nNO-Load Losses (W)  %5.1f',PnL);
fprintf(f2, '\nNO-Load Wattful Current (A)   %5.3f',Iw);
fprintf(f2, '\n-------Magnetizing-Current----------->');
fprintf(f2, '\nlnterpolated values of  at/m of St:Core=%5.1fandTeeth=%5.1f',atsc,atst);
fprintf(f2, '\nlnterpolated values of Caters  Coeffts:k01=%5.3f,k02=%5.3f,kv= %5.3f', k01,k02);
fprintf(f2, '\nStator %5.1f+%5.1f=%5.1f',ATSC,ATST,ATS);
fprintf(f2, '\nRotor AT      :Core+Teetn: %5.1f+%5.1f=%5.1f',ATRC,ATRT,ATR);
fprintf(f2, '\nTotal AT :Stator+Rotor+Airgap: %5.1f+%5.1f+%5.1f=     %5.1f',ATS,ATR, ATg,ATT);
fprintf(f2, '\nNO-Load Current (A) Iw=%5.2f,Im=%5.2f and IO=%5.2f at pf=%5.3f',Iw,Im,I0,Pf0);
fprintf(f2, '\nIO/lph ratio    %5.3f',I0byI);
fprintf(f2, '\n-----Short-Circuit-Current----------->');
fprintf(f2, '\nSlot-Permeances: Stator=%5.3f,Rotor=%5.3f and Rotor refered to stator= %5.3f',Lmdss,Lmdsr,Lmddsr);
fprintf(f2, '\nSpecific-Slot-Permeance=%5.3f',ssp);
fprintf(f2, '\nTotalReactance(X) :Slot+Overhang+Zig-Zag=%5.3f+%5.3f+%5.3f=% 5.3fohms',Xs,X0,Xz,X);
fprintf(f2, '\nShort-Circuit: R=%5.2f,Z=%5.2f and Isc=%5.1f at pf=%5.3f;Isc/IFL=% 5.3f',R,Z,Isc,pfsc,RAT);
fprintf(f2, '\nTotalLosses(PnL+Pcus+Pcur)=%5.1f+%5.1f+%5.1f=%5.1fWandEfficiency=%5.2f perc',PnL,Pcus,Pcur,Pt,eff);
fprintf(f2, '\nSlip at FL =%5.3f X Perc',SFL);
fprintf(f2, '\nStarting Tq    =%5.3f X FL-Tq',Tst);
fprintf(f2, '\nMax.Output(KW)=%5.1f',Pmax);
fprintf(f2, '\nTemp-Rise(deg-C) =   %5.1f',Tr);
fprintf(f2, '\nTotalWt(Kg)=Wcus+Wt+Wc+Wri+Wcur+Wcue=%5.1f+%5.1f+%5.1f+%5.1f+%4.1f+%4.1f=%5.1f',Wcus,Wt,Wc,Wri,Wcur,Wcue,Wtot);
fprintf(f2, '\nTotal Wt(Kg)=%5.1f and Kg/KW=%5.2f',Wtot,KgPkw);
fprintf(f2, '\n<------------End of Output-------->');
end;
```

```
if optim==1
if(sn<12) sn=sn+1;
if eff >=EFFmax EFFmax=eff; end;
if abs(eff-EFFmax)<=2e-3 M2=sn; end;
if KgPkw <=minKgPkw minKgPkw=KgPkw;end;
if abs(KgPkw-minKgPkw)<=0.001 Ml=sn; end;
if Tr<=minTr minTr=Tr;end;
if abs(Tr-minTr)<=0.0001 M3=sn;end;
if I0byI <=minIObyI minIObyI=I0byI;end;
if abs(I0byI-minIObyI)<=0.0001 M4=sn; end;
if(cond_type==1)
if(sn==1) fprintf(f2,'\n Rod conductors are used------>');fprintf(f2, '\n%3d%3d%4.0f%3.0f%4.0f%3d',P,Zs,D,v,L,S);end;
fprintf(f2, '\n%2d%4.1fX%3.1f%4.1f',sn,cond_dia,insS,CDSW);
fprintf(f2, '%5.1fX%2.0f%6.3f%5.1f%4.0f%6.2f%5.0f%6.2f%5.2f%5.2f%5.2f%4.1f',Ws,Hs,Btmax,Tr,DO,eff,Wtot,KgPkw,I0byI,Pf0,pfsc,SFL);
fprintf(f2, '\n--- ------ --------- --- --- ----- ---- ---- \n');
end;
if(cond_type==2)
if(sn==1) fprintf(f2,'\n Bar conductors are used------>');end;
fprintf(f2, '\n%2d%3d%3d%4.0f%3.0f%4.0f%3d%4.1fX%3.1f%4.1f',sn,P,Zs,D,v,L,S,Tstrip,Hstrip,CDSW);
fprintf(f2, '%5.1fX%2.0f%6.3f%5.1f%4.0f%6.2f%5.0f%6.2f%5.2f%5.2f%5.2f%4.1f',Ws,Hs,Btmax,Tr,DO,eff,Wtot,KgPkw,I0byI,Pf0,pfsc,SFL);
fprintf(f2, '\n--- - --------- --- --- ----- ---- ---- \n');
end;
end;end;end;end;
if(sn==12)
fprintf(f2, 'Design Variant based on Optimization Criteria: ');
fprintf(f2, '\n for Max. Eff. Variant (Sn)= %3d (%5.2f perc) ',M2,EFFmax);
fprintf(f2,'\n for Min. Kg /KW  Variant (Sn)=%3d(%5.2f)', M1,minKgPkw) ;
fprintf(f2, '\n for Min Temp-Rise Variant (Sn)=%3d (%4.2f)',  M3,minTr) ;
```

```
fprintf(f2, '\n for Min IOIr ratio Variant (Sn)=%3d (%4.2f)' ,M4,minIObyI) ;
end;
end;end;
fclose (f2) ;
```